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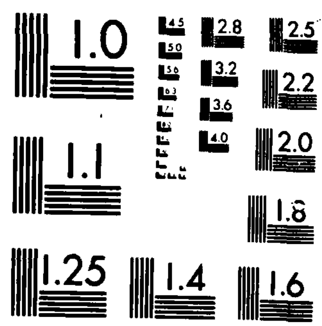

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Nonlinear Elastic and Inelastic Analysis of Structural Members in the Presence of High Temperature and Creep

Final Report

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Principal Investigator

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Alan Kushner, Scientific Officer

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This research began with a mixed principle based creep analysis and was later redirected to a study of limiting performance methodology, including a formulation for the limiting performance analysis of large systems. The formulations for dynamic systems apply to problems for which such variables as maximum displacements or stresses, relative displacements, peak velocities or accelerations are of concern. Keywords:

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ABSTRACT

This research began with a mixed principle based creep analysis. Then the work was redirected to a study of limiting performance methodology, including a formulation for the limiting performance analysis of large systems.

I. INTRODUCTION

The usual design of dynamic systems, e.g., shock and vibration isolation systems for ship foundations, requires the a priori choice of a particular system of fixed configuration. The structural elements forming the chosen system are then optimized to meet prescribed criteria. The possibilities for optimization are limited, however, by the class of elements selected at the outset.

The concept and value of configurationless or true optimal design of dynamic systems have often been recognized by the designer but almost never successfully implemented, especially for large-scale systems. The proposed formulations for dynamic systems, e.g., isolation systems, will apply to problems for which such variables as maximum displacements or stresses, relative displacements, peak velocities or accelerations, etc. are of pacing concern. It is plausible that other optimal design criteria such as minimum weight can be incorporated.

II. FORMULATION

Ideally, system design should follow directly from the design criteria with no a priori commitment on the designer's part to a particular design configuration. In practice, of course, this is not achieved. A procedure is sketched here for the confirgurationless study of large systems subject to dynamic loading.

For a multidegree of freedom system with multiple configurationless elements, the equations of motion become

$$[m]\{\ddot{x}\} + [c]\{\dot{x}\} + [k]\{k\} + [U]\{u\} = [F]\{f\} \qquad (1)$$

where $[U]\{u\}$ contains that portion of the system being designed. These relationships require linear global kinematics, but no linearity requirements are placed on the elements being designed. These elements can be considered to be active vibration isolation elements.

The problem is to compute $\{u\}$ such that certain design objectives are achieved. Subsequently, it is possible that system identification procedures can be used to select (design) the near-optimal isolation system.

More specifically, the systems design problem of interest here is one where we choose portions of the system such that a performance index Ψ of certain reponses h_r is extremized and certain response constraints c_k are satisfied. Typically, the problem is to find $\{u\}$ such that

$$\Psi = \max_t h_r \qquad (2)$$

is minimized subject to

$$C_k^L \le C_k \le C_k^U \qquad (3)$$

where the bounds on the constraints are prescribed.

The calculation of $\{u\}$, such that the optimization problem is satisfied, can be formulated as a linear programming problem. To observe this, note that the objective function (2) is equivalent to imposing the constraint

$$|h_r| \le \Psi \text{ for all } t \qquad (4)$$

The problem is now to minimize Ψ subject to the constraints

$$-\Psi \le h_r \le \Psi \qquad r = 1,2,\ldots \qquad (5)$$

as well as the constraints of Eq. (3).

Upon appropriate discretization, the problem can be placed in a standard linear programming format. This follows because the generic forces $\{u\}$, which are nonlinear in the design space, are linear when discretized in time. Standard linear programming software can be used for the computations. Readily available linear programming codes can routinely handle sets of equations with several thousand inequalities with virtually unlimited variables. Computationally, the significant fact here is the problem of determining the true optimum (limiting performance) of large systems is one of linear programming whose size is independent of the number of degrees of freedom of the system. Rather, it depends on the number of structural components, the number of response constraints, and a factor related to the method employed for time discretization.

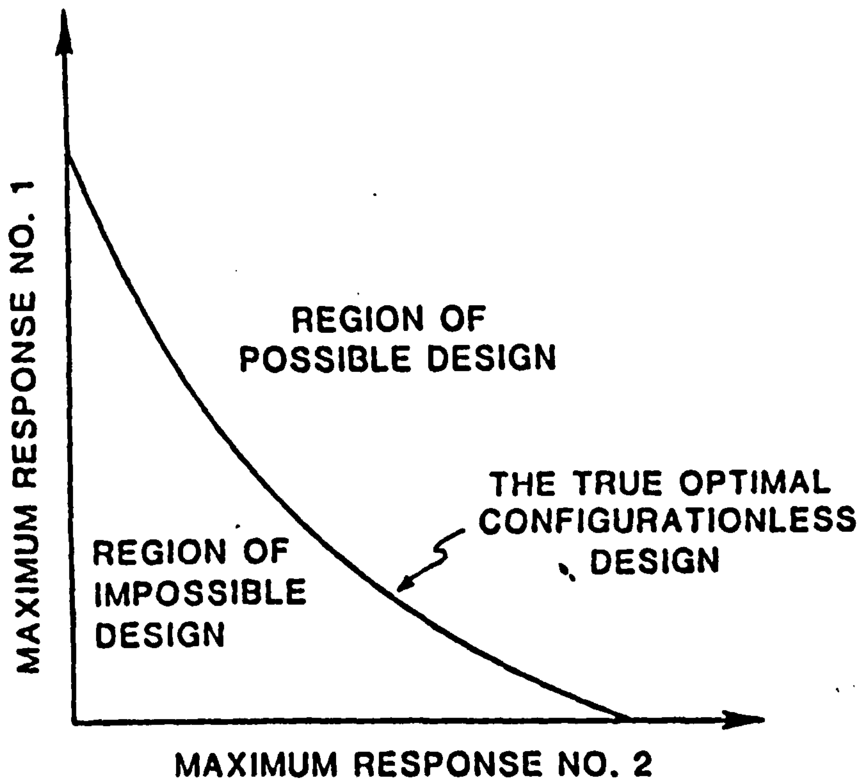

Fig. 1 Limiting performance

A typical result for a limiting performance study is shown in Fig. 1, where a tradeoff between two peak responses (one a performance function and the other a constraint) is illustrated. The value of such information is clear. It is not possible, regardless of configuration, to design an isolation system with performances below the true optimal curve. The actual design configuration can be sought as a second step in the design process such that its response approaches that of the true optimal response. Both passive and active configuration can be considered. For steady state problems, one axis of the limiting performance curve of Fig. 1 may portray frequency.

The study done under this grant concentrated on the formulation of this problem for large scale systems represented by finite element models.

III. SUMMARY OF WORK PERFORMED

A. Numerical Solution for Creep Problems

A new simpler solution procedure was devised for the finite element analysis of creep problems. The creep strains were eliminated as computation variables. At each time step a system is solved for the stresses and velocities alone. This is in contrast to the usual technique, such as used in ADINA, which solves for the stresses, creep strains, and displacements at each time step. In numerical tests this new procedure has been significantly faster than the techniques used in ADINA. See Publication No. 1.

B. A Modal Approach for the Formulation of the Limiting Performance Problem

The limiting performance problem is formulated in terms of the modal response of a system. This permits truly large systems, for which analytically or experimentally determined modal characteristics are available, to be handled. This sets the stage, for example, for coupling a limiting performance study to a shock isolation system being designed with the Navy's DDAM procedures. This limiting performance formulation is implemented using linear programming, which does not impose linearity on a control force yet permits a problem of immense size to be solved. See Publication No. 4.

C. Development of Equations of Motion of the Limiting Performance Study of Complex Systems Including Those Formed of Subsystems

This effort addressed the problem of preparing limiting performance governing differential equations when control forces are embedded in a large system or when the control forces connect subsystems for which modal characteristics are available. This expands the capability of limiting performance to include larger and more complex systems, such as those performed by several systems. See Publication No. 2.

D. Modal Representation of Control Forces

The size of the computational solution of a limiting performance problem does not depend on the number of degrees of freedom of the system. Rather, it is a function of the number of constraints and the manner in which the generic forces are discretized. This is a study of the effect of replacing time disretization of the generic forces with a time series representation based on the natural frequencies of the system. Implementation of a formulation such as this can substantially reduce the computational burden of a limiting performance solution. See Publication No. 3.

E. Analytical Determination of the Limiting Performance

This is the development of a graphical solution for the limiting performance of single-degree-of-freedom systems. Such an analytical approach permits an in-depth study of the characteristics of limiting performance, such as the effect of different excitations. For example, a sensitivity study can be performed of the improvement in response achieved if there is some knowledge beforehand of the excitation.

IV. INDEX OF PUBLICATIONS

1. "An Improved Solution Procedure for Creep Problems", to appear, International Journal of Numerical Methods in Engineering, 1986.

2. "Application of Limiting Performance Concepts to Structural Control Problems", Chapter in Structural Control, Ed: H.H.E. Leipholz, North-Holland, N.Y., 1985.

3. "Limiting Performance of Transient Systems by a Modal Analysis, Modal Control Approach", submitted for publication.

4. "Limiting Performance of Shock Isolation Systems by a Modal Approach", to appear Earthquake Engineering and Structural Dynamics, 1986.

5. "A Direct Method for Estimating Lower and Upper Bounds of the Fundamental Frequency", Shock and Vibration Bulletin, 1985.

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